National Cancer Institute

Nuclear Reactor Accidents: Three Mile Island, Chernobyl

Dosimetry

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U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
National Institutes of Health

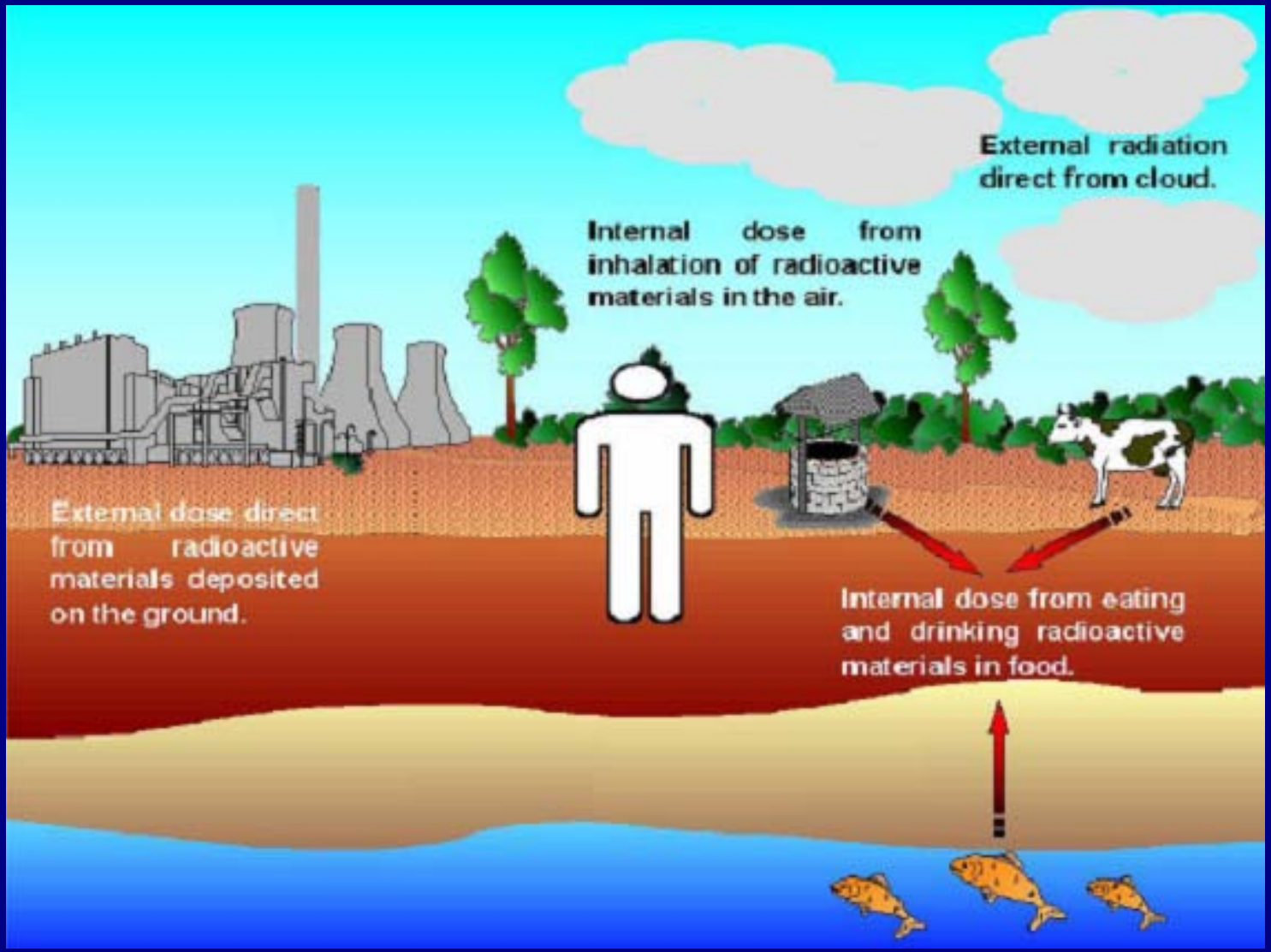
Outline

- Pathways of exposure
- Importance of ^{131}I
- General scheme of dose calculation
- Three Mile Island
- Chernobyl
- NCI Chernobyl Studies

Large releases of radioactivity to atmosphere

- Plutonium production facility:
  - Hanford (USA, 1940s)
  - Mayak (USSR, 1950s)
- Atmospheric nuclear weapons tests:
  - Nevada (USA, 1951-1958)
  - Semipalatinsk (USSR, 1949-1962)
  - Marshall Islands (USA, 1946-1958)
- Reactor accidents:
  - Windscale (UK, 1957)
  - Three-Mile Island (USA, 1979)
  - Chernobyl (USSR, 1986)
  - Fukushima (Japan, 2011)

Pathways of exposure



Important radionuclides

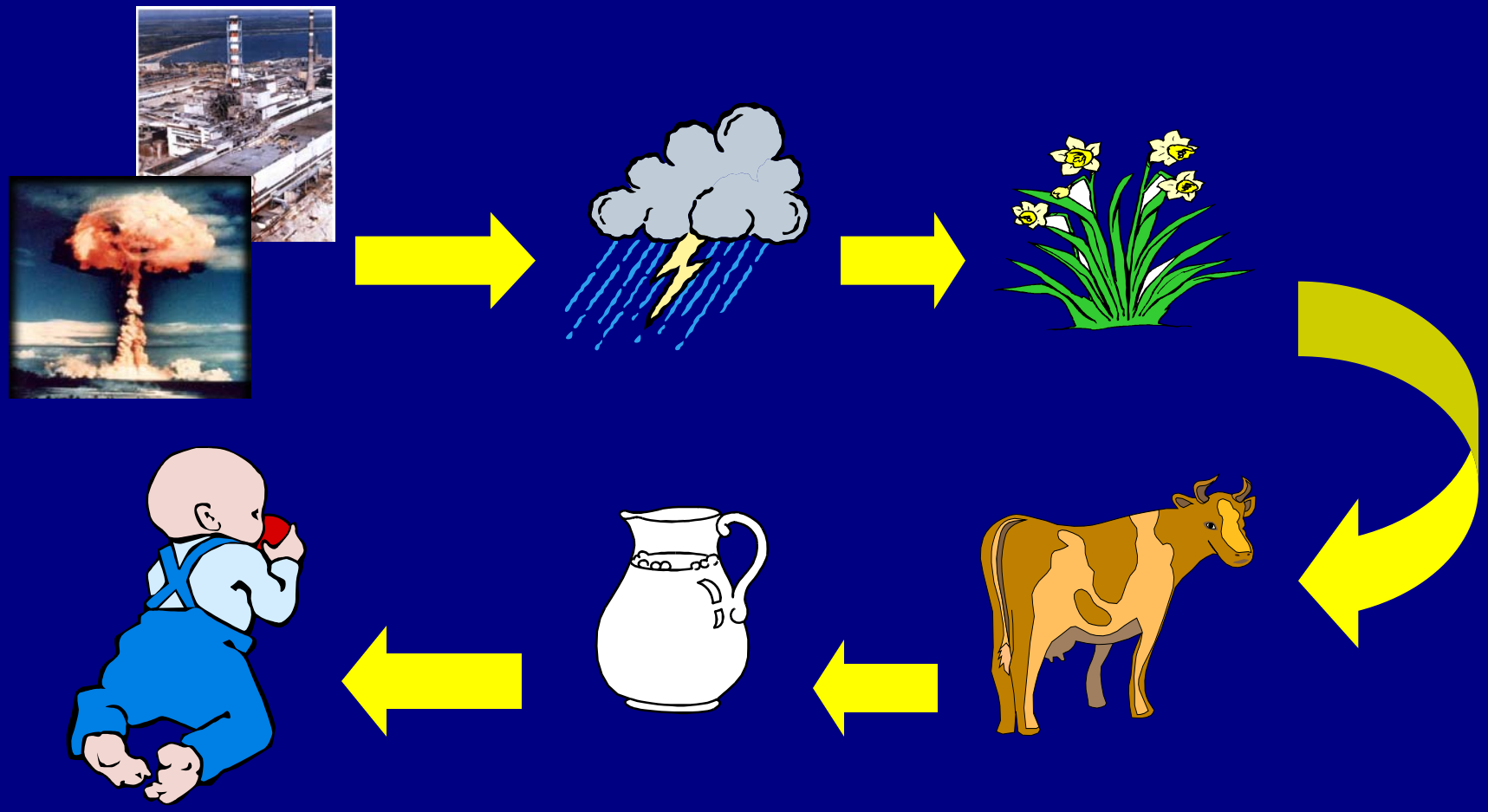
Radionuclide	Half-time	External exposure	Internal exposure
Short-term exposure			
^{131}I	8.04 d	+	+
^{132}Te + ^{132}I	3.26 d	+	+
^{140}Ba + ^{140}La	13 d	+	
^{95}Zr + ^{95}Nb	64 d	+	
Long-term exposure			
^{134}Cs[a]	2.06 y	+	+
^{137}Cs	30.0 y	+	+
^{90}Sr	29.12 y		+

[a] Nuclear reactor release only

Importance of ^{131}I

- Iodine is accumulated in the thyroid gland
- As a first approximation, the thyroid dose from ^{131}I is proportional to the consumption of milk and inversely proportional to the thyroid mass
- Because the thyroid mass increases with age, from 1-2 g in infants to about 20 g in adults, the average thyroid dose decreases with increasing age

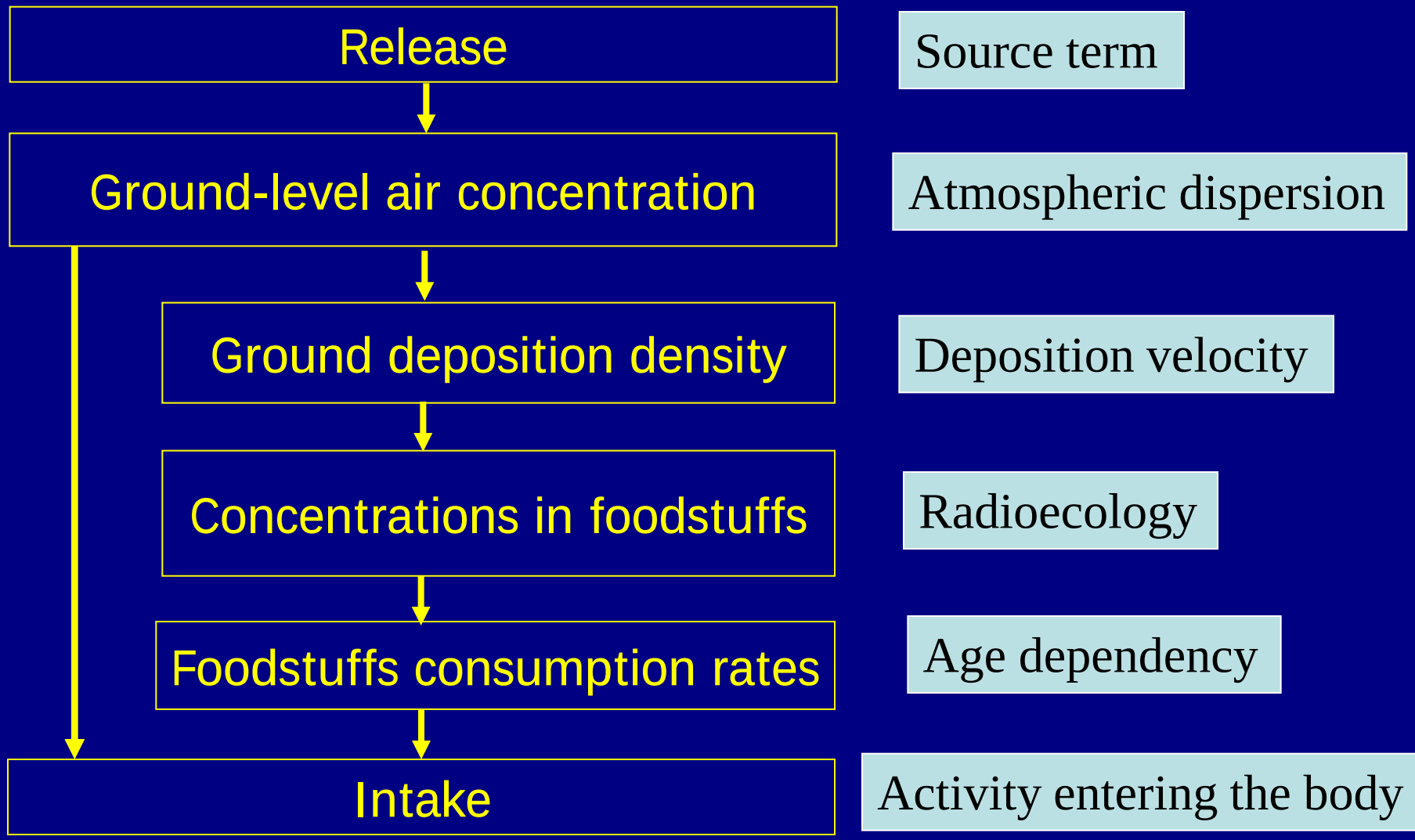
Importance of ^{131}I



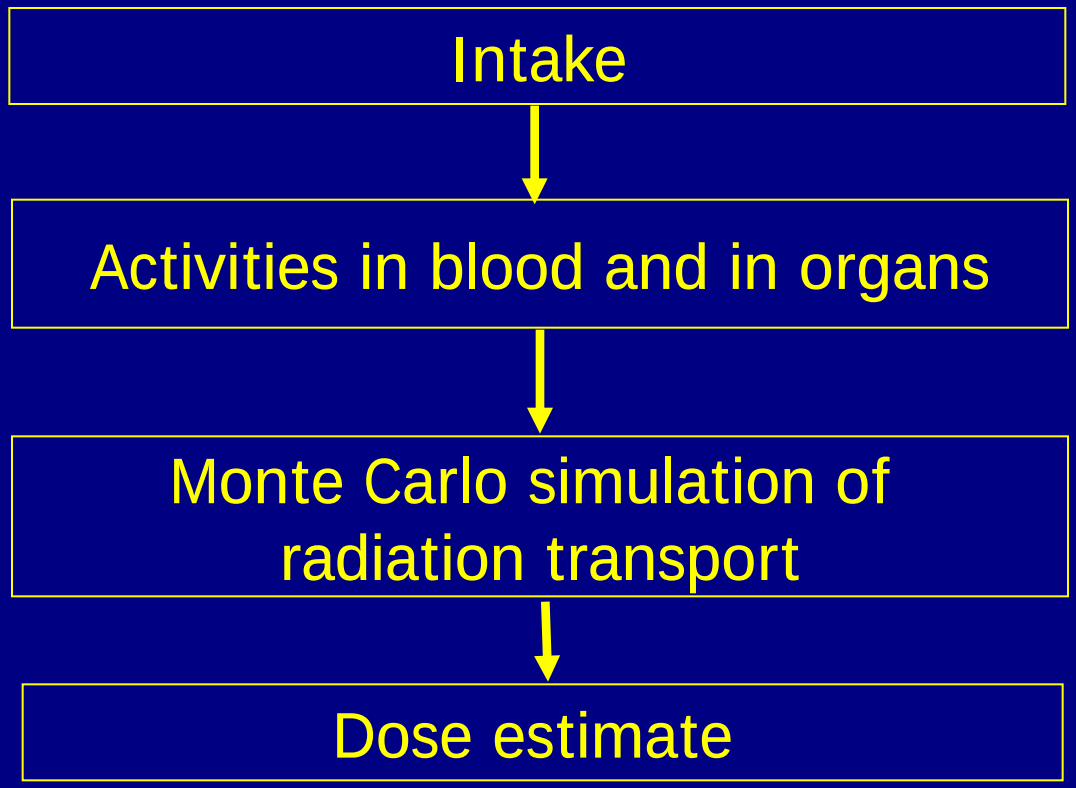
Major releases of ^{131}I to atmosphere

	Release of ^{131}I, PBq
Hanford	15
Mayak	15
Global atmospheric nuclear weapons tests	650,000
NTS tests	5,500
Windscale	1
Three-Mile Island	0.0006
Chernobyl	1,800
Fukushima	???

Internal irradiation: General scheme of dose calculation



Internal irradiation: General scheme of dose calculation (2)



Radionuclide dependent biokinetic models

Use of phantoms

W/ or w/o uncertainty

Types of dose

- For a specified individual:
  - Use of personal interview to collect information on individual whereabouts and consumption history
  - Use of individual dosimeter measurements for external exposure, if available
  - Use of measurements of radioactivity in humans for internal exposure, if available
- For an unspecified individual, representative of a group
  - Use of generic values

Three Mile Island nuclear power plant

Three Mile Island nuclear reactor accident

- Occurred on March 28, 1979 at the Three Mile Island Unit 2 nuclear power plant near Middletown, PA
- The most serious in the U.S. commercial nuclear power plant operating history
- No death or injuries to plant workers or members of public

TMI accident: Activity released (PBq)

Radionuclide	Half-time	TMI
^{85}Kr	10.7 y	2
^{133}Xe	5.25 d	480
^{131}I	8.04 d	0.0006
^{132}Te	3.26 d	Non-measurable
^{133}I	20.8 h	Non-measurable
^{134}Cs	2.06 y	Non-measurable
^{137}Cs	30.0 y	Trace

TMI accident: Doses

Population	Size of population	Mean dose[a] (mSv)
Population (within 2 miles)	~300	0.5
Population (within 3 miles):		
- thyroid dose to 1-y infant	-	0.112
- thyroid dose to adults	-	0.060
Population (within 50 miles)	2,000,000	0.015

[a] Whole body dose otherwise indicated

Gerusky Ann NYAcad Sci, 1981; Miller Radiographics, 1994

Chernobyl nuclear power plant

Chernobyl nuclear reactor accident

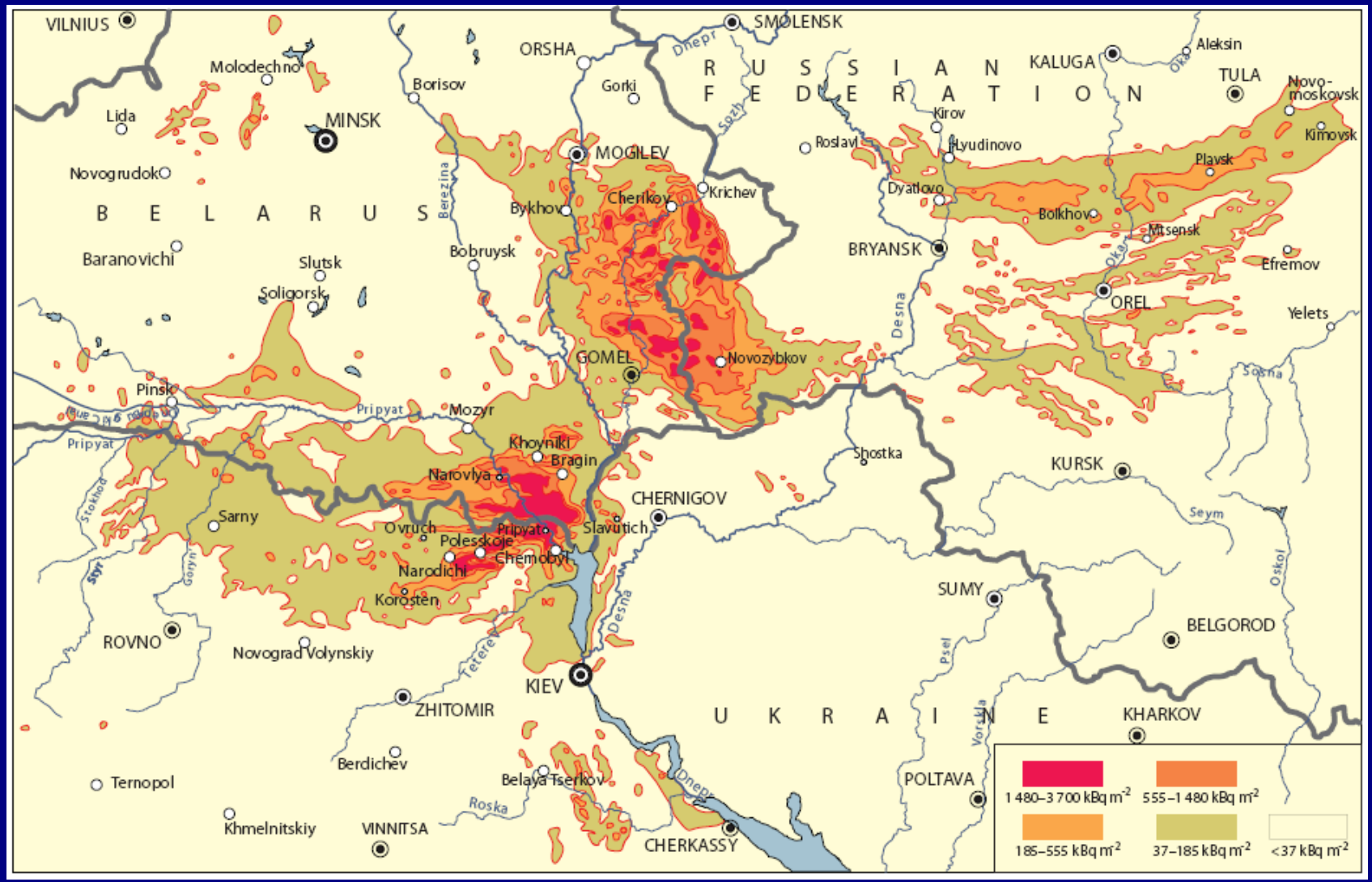
- Occurred on April 26, 1986 at the Chernobyl Unit 4 nuclear power plant in Ukraine
- 2 plant workers died in the immediate aftermath
- High radiation doses to 134 plant and emergency personnel resulted in acute radiation syndrome which was fatal for 28 of them

Chernobyl accident: Activity released (PBq)

Radionuclide	Half-time	Chernobyl	times x TMI
^{85}Kr	10.7 y	33	~18
^{133}Xe	5.25 d	6,500	~13
^{131}I	8.04 d	1,800	~3,000,000
^{132}Te	3.26 d	1,150	-
^{133}I	20.8 h	910	-
^{134}Cs	2.06 y	~47	-
^{137}Cs	30.0 y	~85	-
^{90}Sr	29.12 y	~115	-

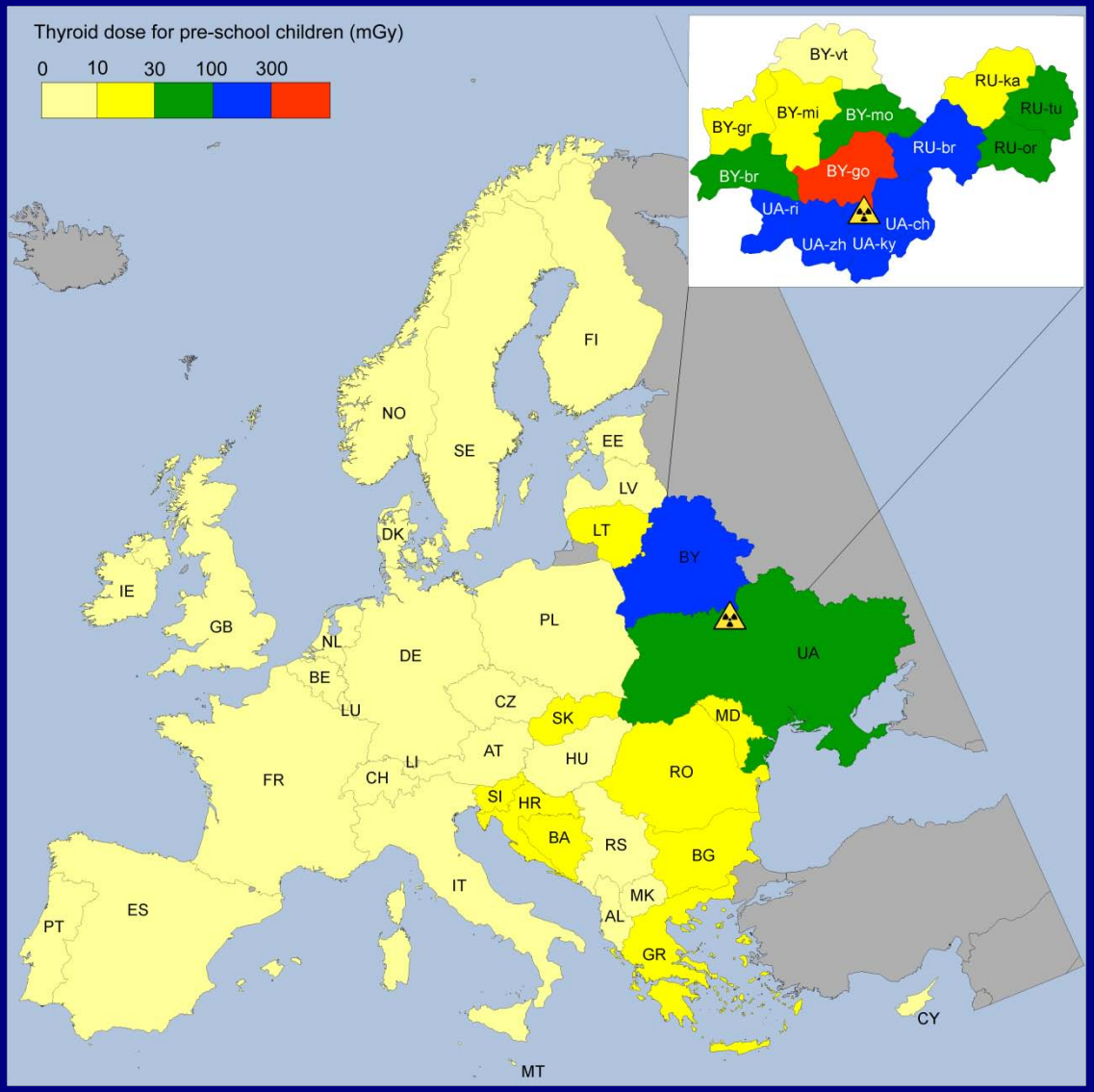
UNSCEAR Report, 2008

Chernobyl accident: Deposition of ^{137}Cs



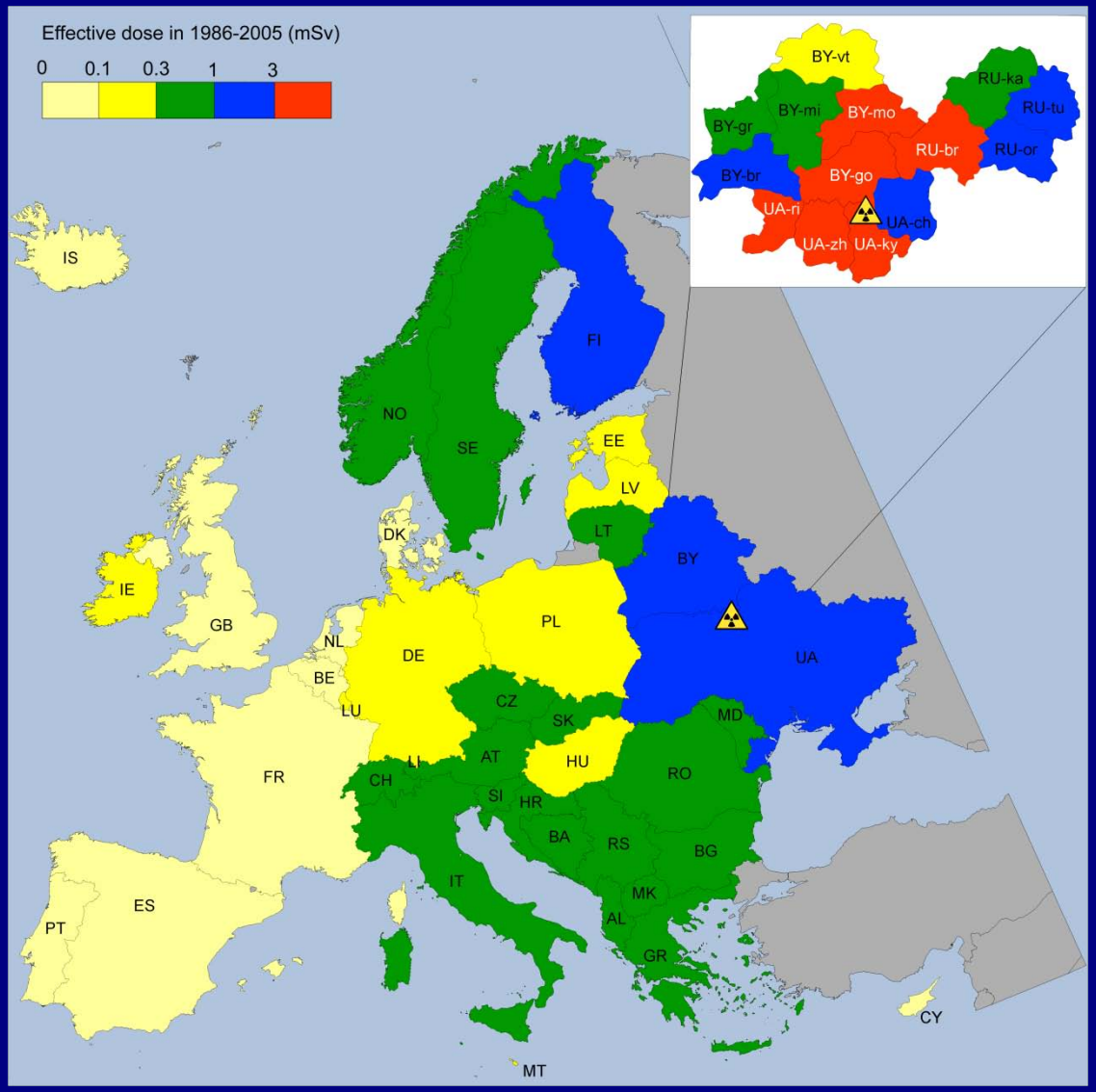
UNSCEAR Report, 2000

Exposure in Europe: Thyroid dose



Drozdovitch et al. Radiat Prot Dosim, 2007

Exposure in Europe: Whole body dose



Drozdovitch et al. Radiat Prot Dosim, 2007

Exposed population groups

Population	Size of population	Mean whole-body dose (mSv)
Liquidators (1986-1987, 30-km zone)	240,000	100
Evacuees of 1986	116,000	33
Contaminated areas in Belarus, Ukraine, Russia:		
- Deposition density of ^{137}Cs >555 kBq/m^2	270,000	50
- Deposition density of ^{137}Cs >37 kBq/m^2	5,200,000	10
Distant countries in Europe	500,000,000	0.3

Cardis et al. J Radiol Prot, 2006

Thyroid doses (mGy) for population groups

Population	Size of population	Preschool children	Adults	Total
Evacuees	116,000	1800	290	480
Belarus, villages	24,700	3100	680	1000
Ukraine, Pripyat-town	49,400	970	70	170
Ukraine, villages	41,900	2700	400	650
Belarus				
Entire country	10,000,000	150	40	50
Gomel region	1,680,000	610	150	220
Ukraine				
Entire country	55,000,000	-	-	10
Region around ChNPP	500,000	-	-	380
Russia, Bryansk region	1,500,000	160	26	40

Cardis et al. J Radiol Prot, 2006

Countermeasures: Early phase of the accident

Countermeasure	Population	Population size	Time since the accident
Sheltering	Pripyat-town	49,400	
Evacuation	Pripyat-town	49,400	37 – 40 h
	30-km zone	49,400	6-11 d
	70-km zone	17,200	1 mo +
Administration of stable iodine	Pripyat-town	49,400	< 37 h
	30-km zone	66,600	No
	outside 30-km	-	No
Control of ^{131}I in milk	affected area	-	10 d +

Countermeasures: Intermediate and late phase of the accident

Countermeasure	Population	Population size	Time since the accident
Decontamination	-	500 villages[a]	< 3 y
Relocation[b]:			
- Belarus	> 555 kBq m^{-2}	110,000	3 y +
- Ukraine	> 555 kBq m^{-2}	72,000	3 y +
- Russia	> 555 kBq m^{-2}	52,400	3 y +
Ban on milk consumption	> 555 kBq m^{-2}	250,000	2 -5 y
Distribution of uncontaminated foodstuffs	> 555 kBq m^{-2}	250,000	2 -5 y

[a] In Belarus

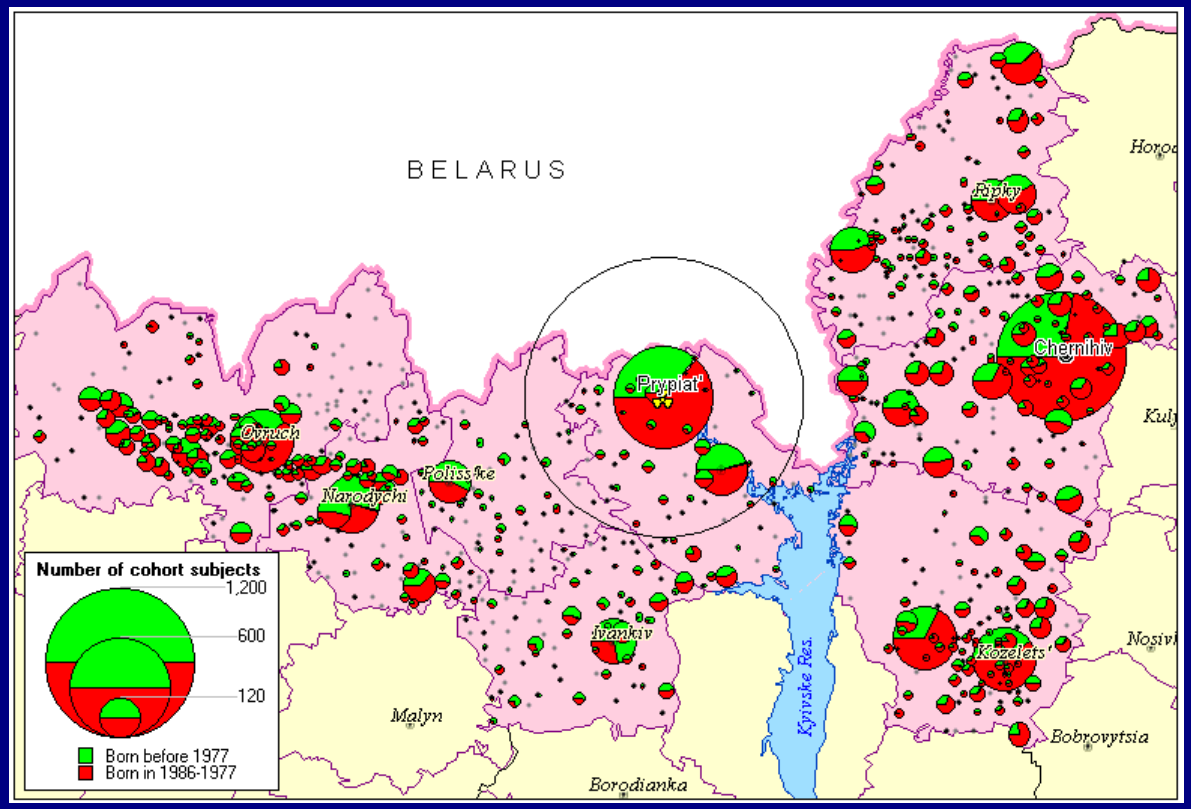
[b] Including voluntary relocated persons

NCI Chernobyl studies

- Cohort study of thyroid cancer and other thyroid diseases in persons who were exposed in childhood and adolescence in Belarus and Ukraine
- Study of thyroid cancer in persons who were exposed *in utero* in Ukraine
- Case-control study of leukemia in male clean-up workers in Ukraine

Thyroid cohort study

- About 25,000 individuals exposed as children: ~12,000 in Belarus and ~13,000 in Ukraine
- Lived in contaminated areas

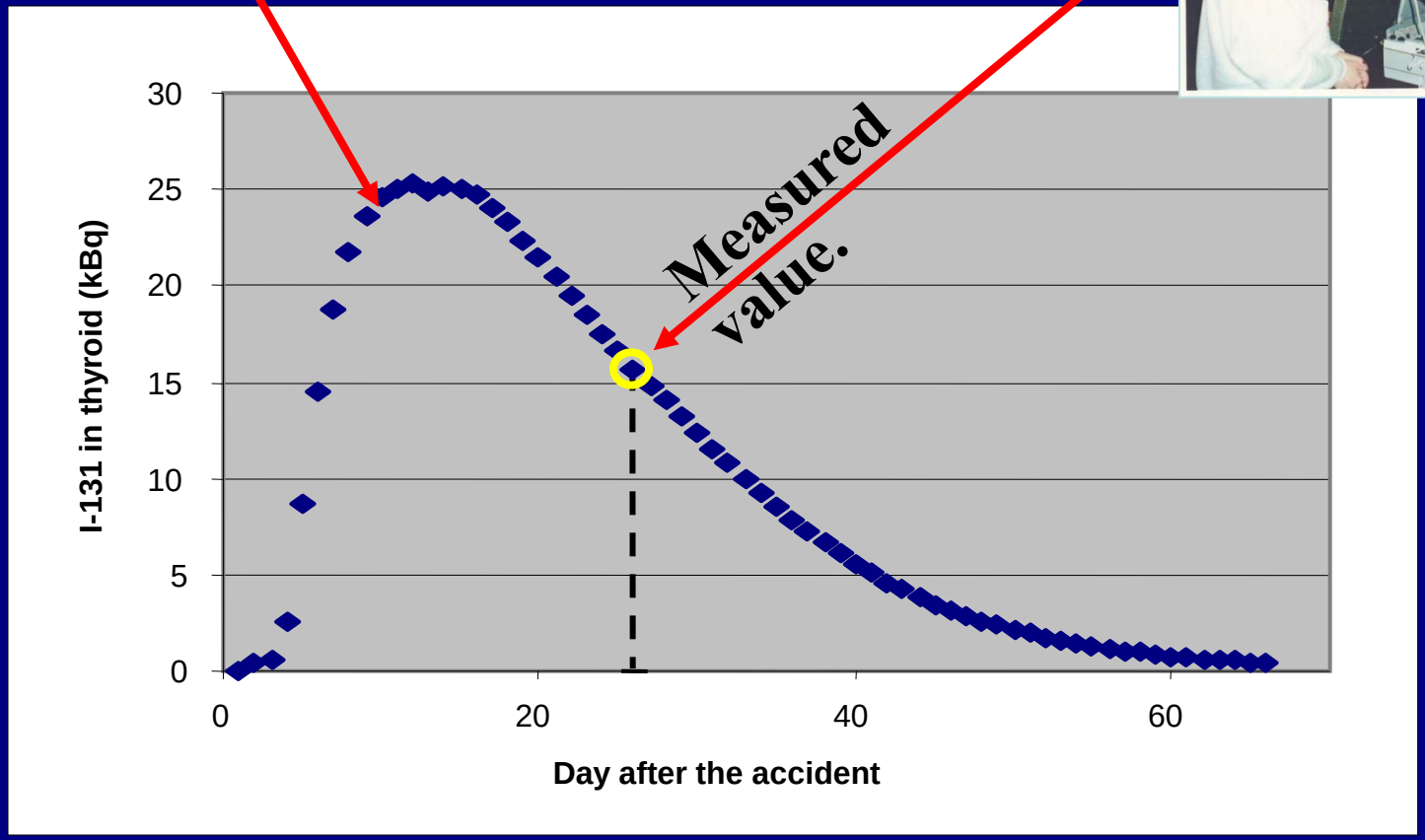


Thyroid cohort study: Dose estimation

- The thyroid dose was mainly due to the consumption of fresh cow's milk contaminated with ^{131}I (half-life of 8.04 days)
- The thyroid dose was essentially delivered within two months after the accident
- Based on the analysis of direct thyroid measurements for all subjects

Direct thyroid measurement

Curve derived from ^{131}I models plus data from questionnaire

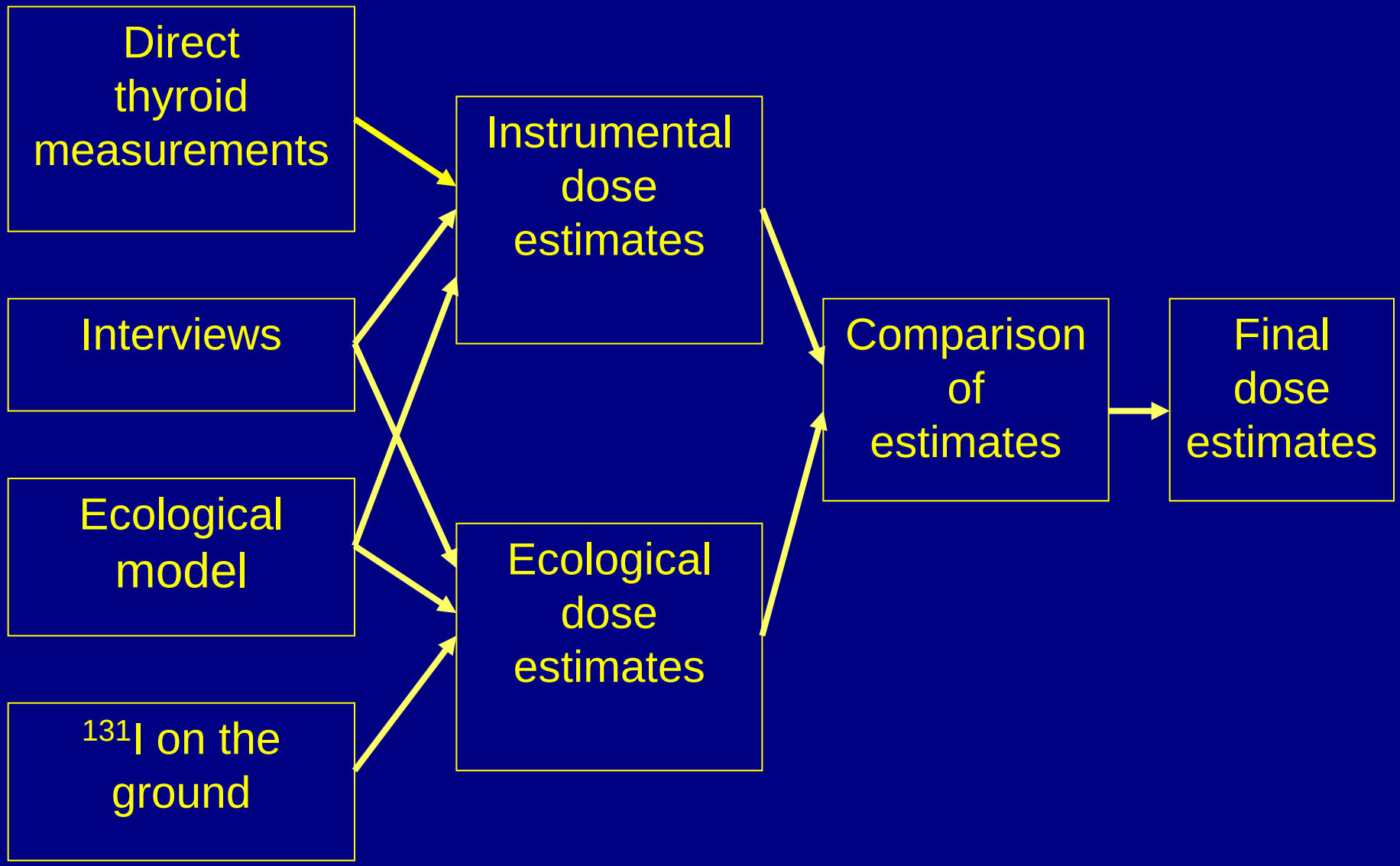


Thyroid dose is proportional to area under the curve

Personal data

- Residence history during the first two months following the accident
- Consumption rates and origin of milk, milk products, and leafy vegetables
- Stable iodine administration, if conducted

Cohort study: Scheme of dose calculation



Thyroid doses from ^{131}I intakes

Dose range (mGy)	Belarus		Ukraine	
	N	%	N	%
200	5,412	46.1	6729	51.0
200 – 500	2,868	24.4	2829	21.4
500 – 2,000	2,814	24.0	2735	20.7
2,000 – 10,000	613	5.2	838	6.3
> 10,000	34	0.3	73	0.6
Total	11,741	100.0	13,204	100

Minenko et al. (in preparation); Likhtarev et al. (in preparation)

Mean thyroid and whole-body doses in Belarusian cohort (mGy)

Pathway of exposure	Thyroid	Whole-body
Intakes of ^{131}I	580	1
Short-lived (^{132}Te + ^{132}I, ^{133}I)	24	0.1
External irradiation	10	10
Ingestion of Cs isotopes	3	3
Total	617	14

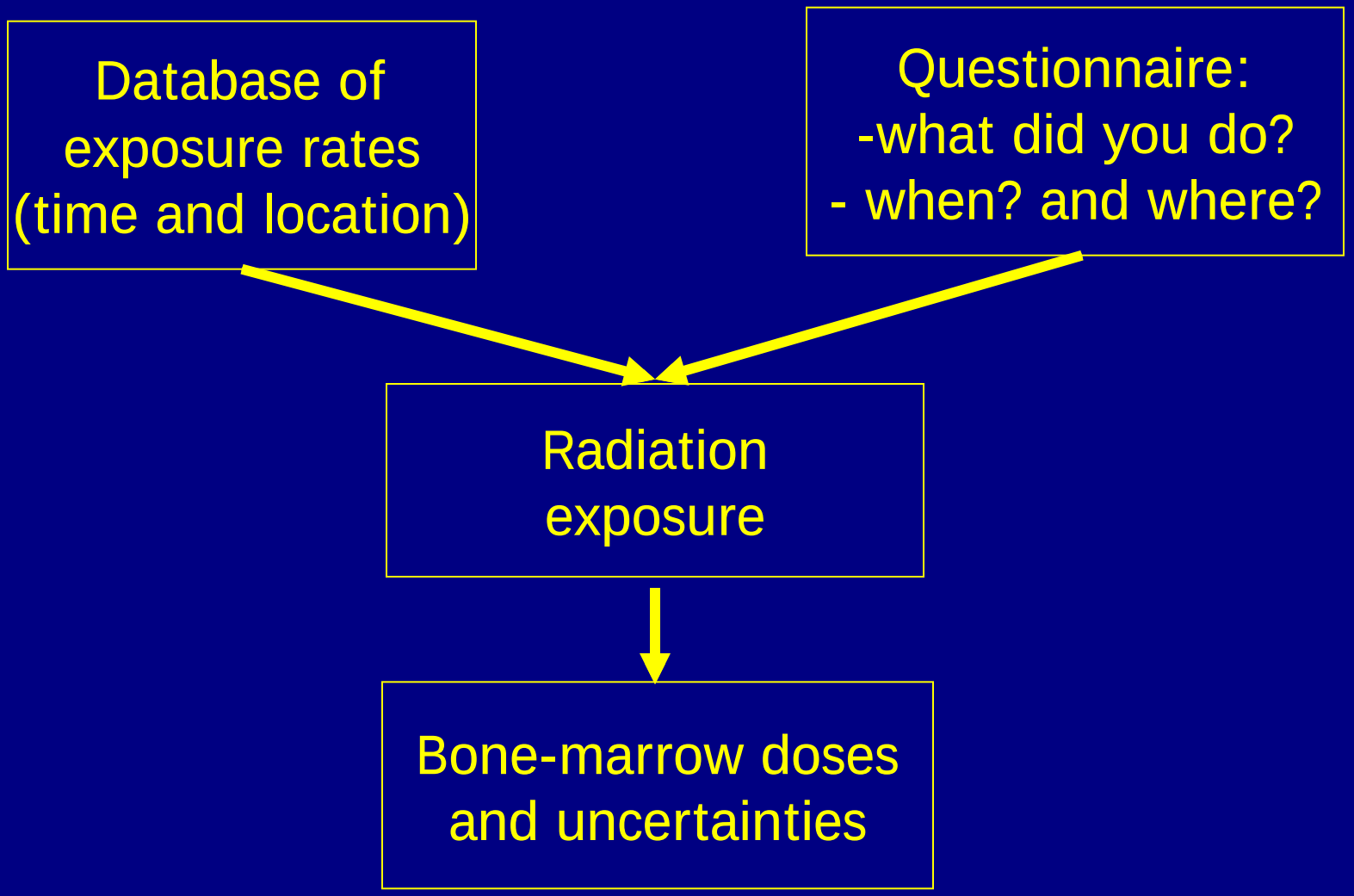
Leukemia study among Chernobyl clean-up workers in Ukraine

- Cohort of 110,000 clean-up workers in 1986-1990
- Were sent by various military and civilian organizations and assigned to a variety of tasks
- Exposed mainly to external irradiation

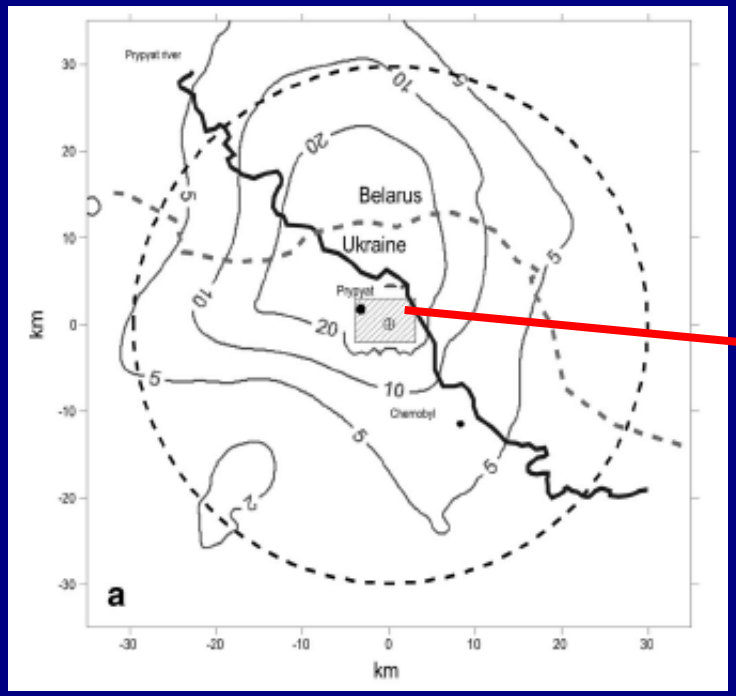
Leukemia study among Chernobyl clean-up workers in Ukraine (2)

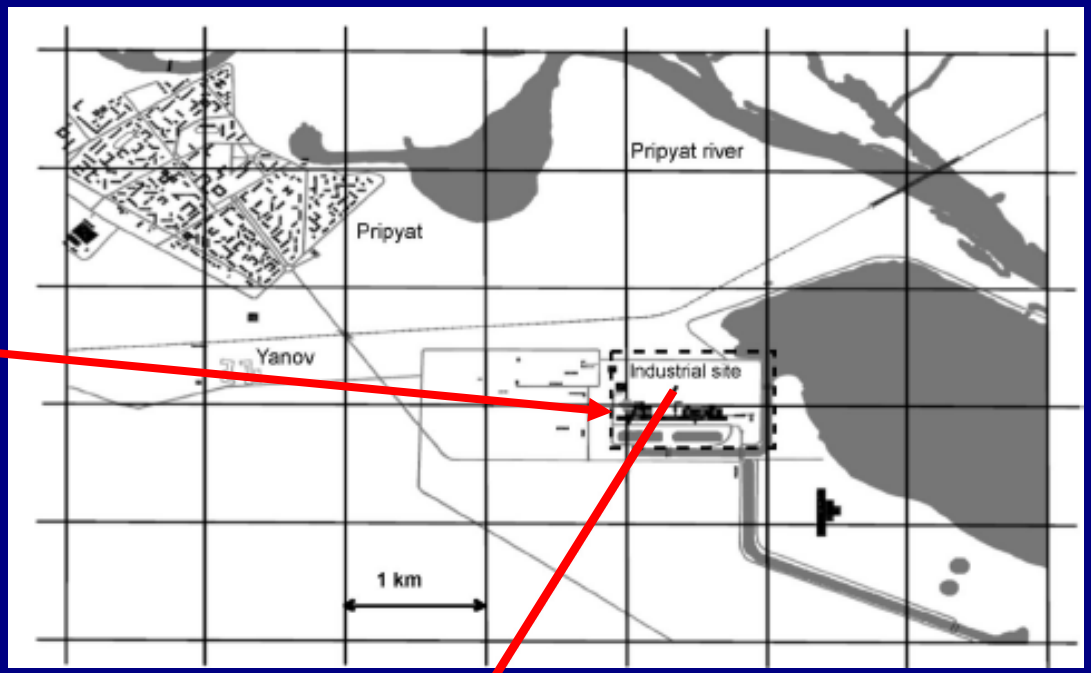
- Case-control study among 1003 clean-up workers: 137 cases and 866 controls
- Dosimetry records not available for 60% of the subjects, and also inadequate
- New method developed – RADRUE (Realistic Analytical Dose Reconstruction with Uncertainty Estimation) – time-and-motion method

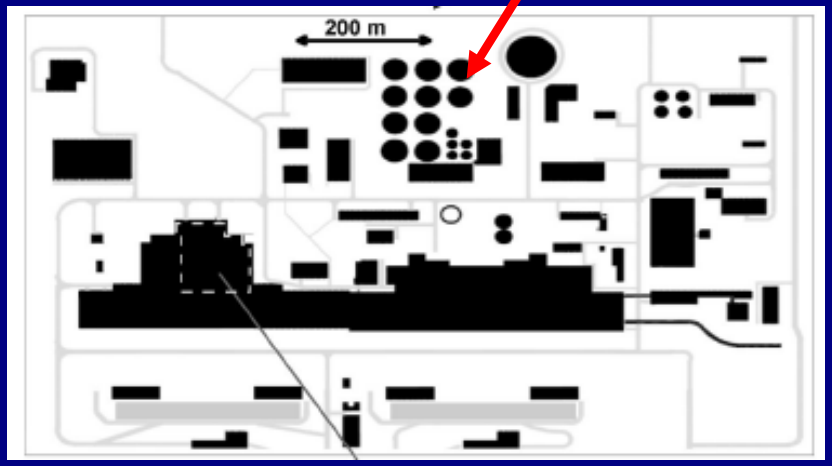
Time-and-motion method (RADRUE)



Basemaps of 30-km zone, 4-km zone, and industrial site







Kryuchkov et al. Health Phys, 2009

Leukemia study: Bone-marrow doses

	Number of workers	Bone-marrow dose (mGy)		
		Mean dose	Min. dose	Max. dose
Phase I (cases)	72	150	0.00004	3200
Phase II (cases)	65	121	0.031	1500
Phase I (controls)	501	78	0.007	3300
Phase II (controls)	365	104	0.005	2100
Total (cases)	137	136	0.00004	3200
Total (controls)	866	89	0.005	3300

Chumak et al. Radiat Res, 2008

Thank you for your attention